CIRCULAR No. 426 MAY 1937
UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

USE OF SOIL-MOISTURE AND FRUIT-GROWTH RECORDS FOR CHECKING IRRIGATION PRACTICES IN CITRUS ORCHARDS

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CONTENTS

SOIL-MOISTURE CONTROL

Soil-moisture determinations have been used in checking the needs of citrus trees for irrigation more, perhaps, than with any other crop. Various methods and a variety of equipment are used. This circular is intended to serve as a guide to citrus orchardists who desire to effect a more accurate control of soil moisture. It describes experiments showing that the growth rate of fruit used in conjunction with soil-moisture determinations provides a more accurate index of the need of the trees for moisture than does soil sampling alone. The equipment and procedure for making fruit-growth measurements and the application of the results are described.

In many situations water is delivered on a regular schedule and the grower simply checks the effectiveness of his irrigation by examining the soil before and after irrigation. The inspection before irrigation indicates in what zones the soil is driest and to what depth irrigation water should be made to penetrate. The irrigator can then make an effort to obtain the necessary penetration by testing for depth of penetration while the water is actually on the land.

Where water can be obtained on demand, or where the water service is somewhat flexible, many growers take soil samples at selected locations in the orchard and base estimates of the need for irrigation on the results of moisture determinations made thereon. Some arbitrary standard is set up; for example, it may be assumed that irrigation is needed whenever the second foot of soil in the irrigated area at the selected sampling location reaches the wilting point. The wilting point is generally obtained by making a moisture-equivalent determination in the laboratory and dividing the result by the factor 1.84. For many soils the moisture equivalent represents the field capacity of the soil under test, that is, the percentage of moisture the

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soil holds after rain or irrigation. Most work of this character done in the citrus areas of southern California is performed by operators of commercial laboratories. The application of soil-moisture records in orchard irrigation requires much practical experience and the success of the method depends to some extent upon the judgment of the operators rendering the services.

Perhaps the principal factor impelling the use of soil-moisture control in the citrus areas of the Southwest is the need for economy in the use of water (*1, 3*).[1] The total seasonal use of water is usually less with less frequent irrigations; hence intervals between irrigations are prolonged as much as possible. The calculated wilting point has been generally used as the safe lower limit to which the soil-moisture content may be reduced before irrigation.

RANGE OF SOIL MOISTURE READILY AVAILABLE TO TREES

The principle of a wide range of readily available moisture is substantiated by the results of Veihmeyer's work (*10, p. 276*) in the Santa Clara Valley, Calif.

> The soil-moisture records presented here indicate that the use of water by mature prune trees does not seem to be influenced by the amount of water present in the soil, provided the soil-moisture content has not been reduced below the wilting coefficient.

Beckett, Blaney, and Taylor (*2, p. 50*), working with citrus and avocados in San Diego County, Calif., also found that

> As long as the soil moisture is above the wilting point, the moisture content has no measurable effect on the rate of moisture extraction; that is, moisture is as readily available when the moisture content is one-third or two-thirds of the way between field capacity and the wilting point as it is in thoroughly moistened soil after irrigation.

Veihmeyer and Hendrickson (*13, p. 7*) concluded from experiments with peach, prune, and apricot trees that—

> Our experiments show that water may be used by plants with equal facility throughout the entire range of soil-moisture contents between the field capacity and approximately the permanent wilting percentage.

While this general principle has been well established by experimental work, its application to practical orchard conditions has not always met with success. Many modifying factors are encountered. Citrus trees are grown on a variety of root stocks and orchards are planted on soil types varying over extreme ranges from coarse, stony, wash soils to heavy clays. Some soils are fairly homogeneous to a considerable depth, while others are composed of layers of entirely different materials. A sandy loam of recent alluvial origin may be underlain with coarse sand at depths of 1 to 3 feet, but older alluvium that has been altered by weathering may have a compact subsoil a foot or more below a topsoil of loose, sandy loam. The rooting habits of trees vary greatly under these different conditions and the reaction of the trees varies accordingly. In making practical use of the principle of readily available moisture, a knowledge of the root activity and root distribution of the orchard trees under consideration is essential.

The principal evidence supporting the broader generalization regarding the availability of soil moisture at moisture contents above the wilting range has been obtained from determination of the rates of

[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

extraction of soil moisture. In soil zones where feeder roots are plentiful, the moisture content may be reduced to approximately the wilting point without a reduction in rate of soil-moisture extraction. In many orchards the distribution of roots so lacks uniformity that the trees may suffer water shortage even when the average moisture content of the soil is relatively high, because those parts of the soil with a low concentration of roots remain moist for a long time while those with a high concentration of roots dry out quickly and cease to supply the tree with moisture. An illustration of reduced growth rate of fruit caused by water shortage at relatively high average soil-moisture contents has been reported by Lewis, Work, and Aldrich (*6*) working with pears on a heavy clay soil at Medford, Oreg.

It has been demonstrated, by growing small lemon trees in pots under uniform conditions of light, temperature, and relative humidity, that the rate of transpiration stays about the same in spite of decreasing soil-moisture content until the plants show temporary wilting. As the soil dries out, the force required to extract water from the soil increases slightly, but the suction force of the plant tissues also increases slightly and thus the plant may continue to extract water from the soil at approximately uniform rate until the moisture content of the soil has been reduced to near the wilting range. The range of soil moisture from field capacity down to the wilting range is referred to as readily available moisture.

Below the range of readily available moisture lies a narrow range in which wilting occurs. As the soil-moisture content is reduced within this wilting range (*9*), the force holding water in the soil increases abruptly. The plant must then exert a correspondingly greater force to move water out of the soil and the water content of the leaves is reduced to a point where wilting occurs. From this it would seem that wilting of trees might occur rather abruptly as readily available moisture becomes exhausted. This does occur in pot experiments, and even in the field if the roots are confined to a shallow layer of soil, densely filled with roots. This condition may be found where soil is underlain by hardpan, rock, or coarse sand through which roots will not penetrate readily.

In the field, however, it is not the usual condition, as roots are usually distributed unevenly through the soil and the density of feeder roots gradually decreases with increasing depth. In the upper zones of soil with high concentrations of feeder roots there may be a rapid withdrawal of the readily available moisture, while the deeper zones of soil with fewer roots yield water more slowly. Considerable portions of the upper zones may be depleted of readily available moisture without distress being apparent in the tree. However, as more of the root zone falls into the wilting range the moisture deficit becomes increasingly evident. A gradual rise in suction force may be measured by determinations on fruits. Soil samples taken concurrently will show increasing portions of the soil having a moisture content within the wilting range, and yet the continued supply of moisture to the tree from the deeper zones may defer wilting for weeks and even months in some cases.

An indication of the degree to which stress for water has progressed may be had by noting how far the soil-moisture content has been reduced into the wilting range in the portions of soil with high concentrations of feeder roots. Reactions of the tree may be measured

by changes in the apparent growth rate of immature fruits. When the moisture content of the leaves is reduced by rapid transpiration or by a restriction in the water supply from the soil, the suction force in the leaves rises. Water is then withdrawn from the fruit to the

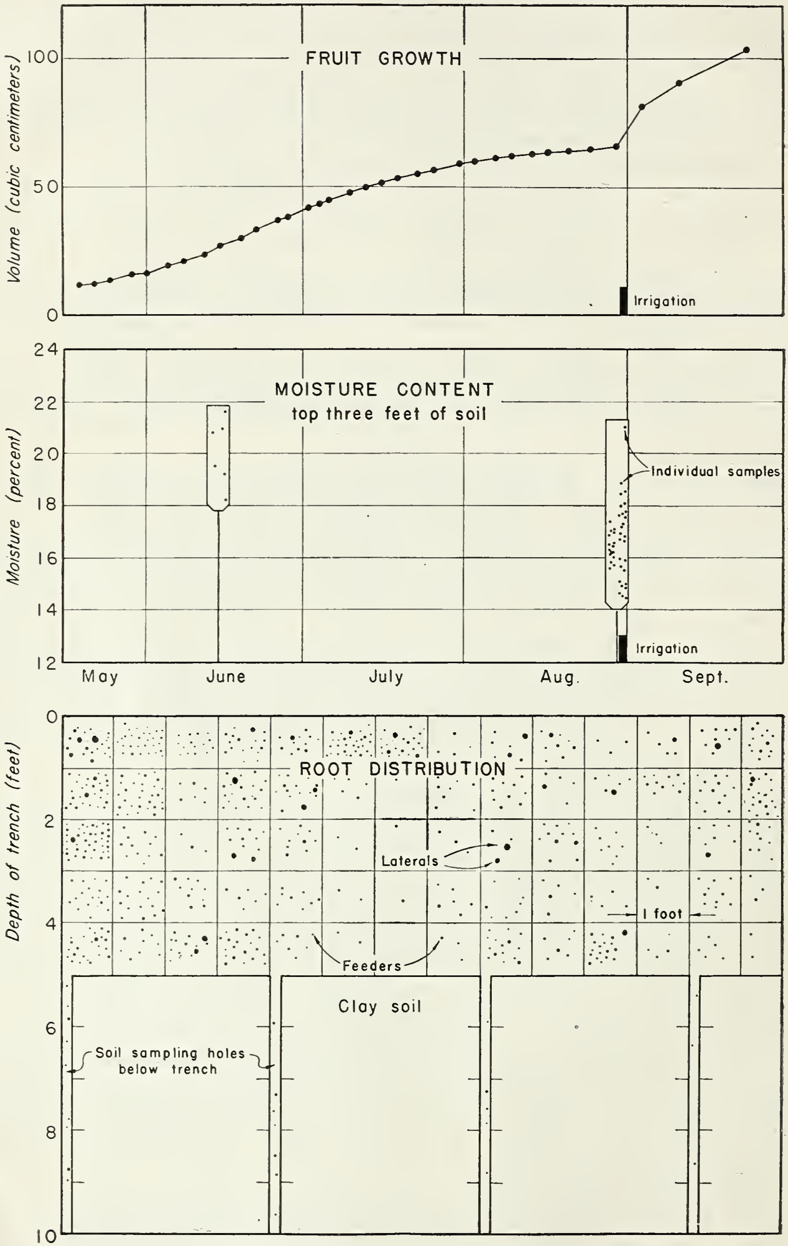

FIGURE 1.—Fruit growth, soil moisture, and root distribution in lemon orchard S, on a clay soil at San Dimas, Calif., 1935.

leaves and this loss of water causes the fruit to shrink. This shrinkage may be easily measured.

Figures 1 and 2 illustrate how fruit growth responds to irrigation on a heavy soil with deep-rooted trees and on a light soil with shallow-rooted trees. There was a marked difference in the behavior of the trees on these two soil types. The supply of readily available moisture was depleted rather quickly on the lighter soil type with the underlying layer of coarse sand. But on the heavier soil there was a slow and long-

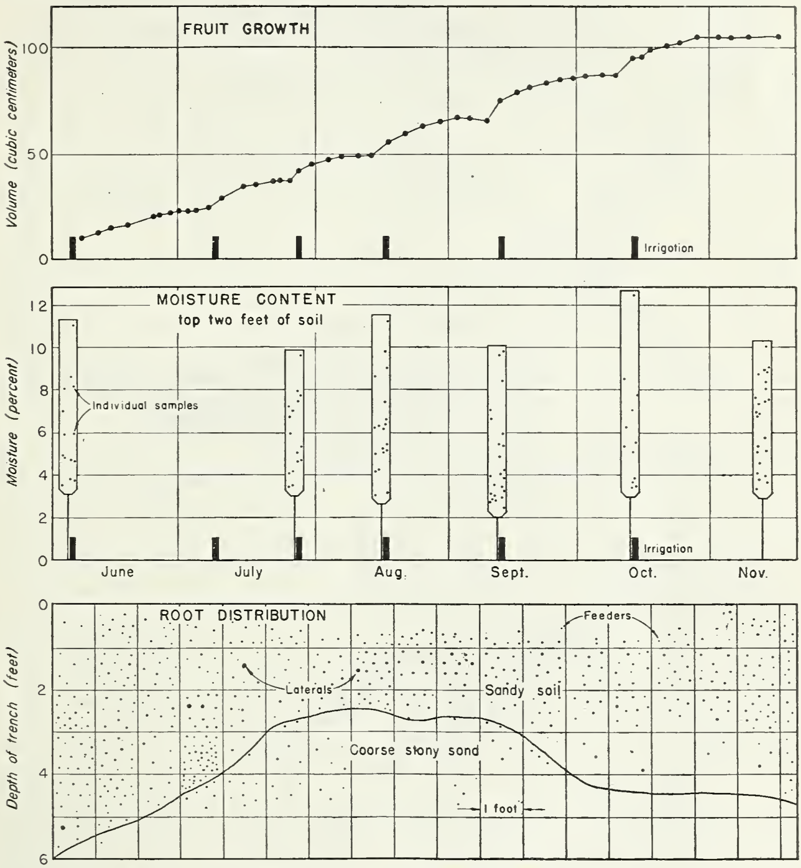

FIGURE 2.—Fruit growth, soil moisture, and root distribution in lemon orchard W, on a sandy soil at Claremont, Calif., 1935.

continued supply of moisture that was taken in by the deeper roots after the readily available supply in the upper zones had been exhausted. The fruit in orchard S continued to enlarge for 165 days after the soil was at field capacity from spring rains, while in orchard W it ceased to enlarge or was actually shrinking 25 days after the irrigation on August 15. The charts of roots were obtained from trenches. Trenching is an excellent way to examine soil profile and rooting habits, and the added knowledge will well repay the orchardist for the effort.

The plottings of soil moisture shown in figures 1 and 2 indicate considerable variation from point to point. In orchard W the stony nature of the soil made sampling difficult. All of the rock with a

diameter greater than 2 millimeters was screened out of these samples and the moisture percentage calculated on the basis of the oven-dry weight of the remaining finer material. High moisture content persisted at certain of the sampling locations and the wide variation makes it difficult to determine the need for irrigation from the soil-moisture records alone. However, the low values of moisture content found in zones of high root concentration in areas under trees

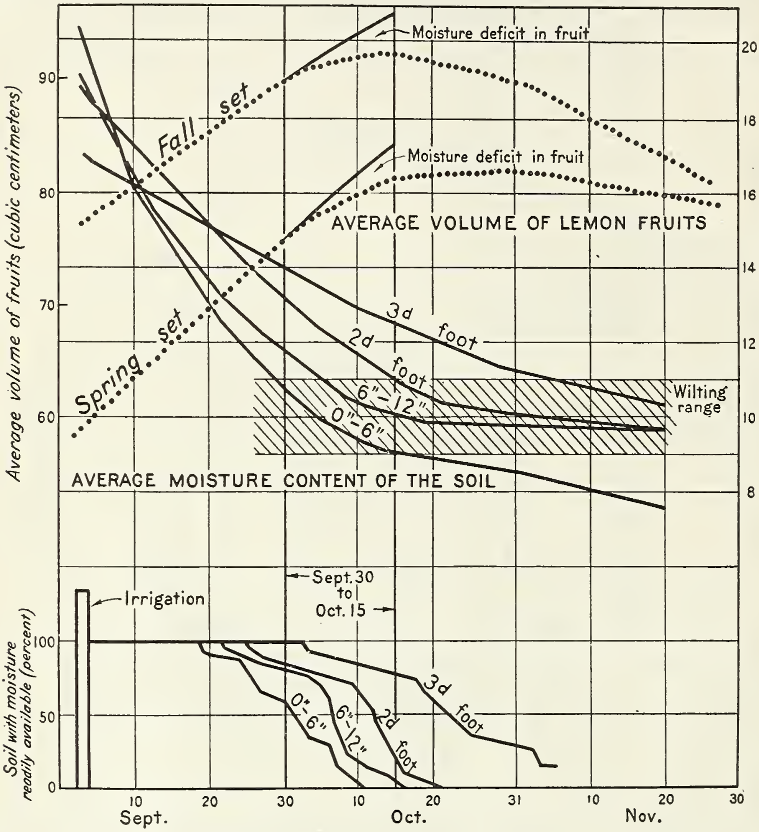

FIGURE 3.—Relation of growth of lemon fruits to soil-moisture conditions in an orchard on a medium soil type at San Dimas, Calif., 1933.

may be taken as an indication that the tree was under a relatively severe stress for water. In this soil a moisture content below 4 percent gives evidence of severe stress for water. Field capacity is 14 percent when based on the oven-dry weight of the material finer than 2 millimeters. In orchard S the field capacity is 26 percent, and a moisture content below 18 percent is evidence of need for water.

Figures 1 and 2 show conditions on typical orchards that are widely variant as to soil type, rooting habits, and irrigation needs. Figure 3 illustrates conditions in a medium soil type—a clay loam with a field capacity of 19 percent. This chart shows the relation of fruit growth to a gradually decreasing amount of moisture in the soil. Here both fruit growth and soil moisture were studied in great detail. Over 1,500 soil samples were taken around one tree in a period of 3

months. This was done in order to get a measure of the proportion of soil in various depth zones that was above or below certain critical moisture percentages. A cover crop was grown on this plot in order that there might be active roots in all parts of the soil.

For a period of 28 days following irrigation the fruit grew regularly although the moisture content of the soil was gradually decreasing. By October 1 a large portion of the readily available moisture had been extracted from the soil, and in 50 percent of the top 6-inch zone of soil the moisture content had been reduced below the range of readily available moisture. On that date 20 percent of the second 6 inches of soil, 15 percent of the second foot, and none of the third foot had moisture content in the wilting range. This shows how some portions of the root zone may have all of the readily available moisture removed without any measurable restriction in growth of fruit.

Between October 1 and 15 the moisture content in nearly all of the top 2 feet of soil was reduced into the wilting range, and by October 23 all the readily available moisture in that depth had been used up. During this period an increasing moisture deficit was apparent in the fruit as shown by a decline in growth rate. This is evidence of the increasing suction force the leaf cells were exerting in their pull for water needed to replace that lost in transpiration. Increasing amounts of water were then being taken from the fruit. The usual practice would have been to irrigate sometime between October 1 and 15, but this tree was dried out further in order to measure its reaction to conditions of extreme drought. There was no sudden wilting in this case. The gradual restriction in the moisture supply extended over several weeks. Apparent rate of fruit growth decreased gradually between September 30 and October 15. After October 15 the older fall-set fruits were decreasing in size and this shrinkage was large as the soil became very dry. This is a typical reaction for a citrus tree under such conditions. It is evident that both soil moisture and fruit growth may give advance indication of impending water shortage.

A combination of both soil-moisture and fruit-growth records is highly desirable in checking irrigation practices. Soil sampling is most practicable on deep uniform soils that are relatively free from large rocks. A fairly complete occupation of the soil by roots is also desirable when a minimum of sampling is to be used. When soil is variable, or excessively rocky, or root distribution is poor, soil-moisture records are more difficult to interpret. Fruit-growth records may then be the best measure of the effectiveness of irrigation practice. In the case of deep-rooted trees on a uniform soil, fruit growth slows down very gradually and it is often difficult to determine from fruit-growth records alone when water shortage is first indicated; but these conditions are the most favorable for the use of soil-moisture determinations as a guide to irrigation practice, since the tree will not suddenly run out of water, and some leeway is left for choosing the date of irrigation. In other situations, principally in rocky soils, soil sampling may be inadequate, and in most cases fruit-growth records will then be more reliable. On the coarser soil types the bending of the fruit-growth curves is more abrupt when stress occurs, and the need for irrigation is shown more definitely. The use of fruit-growth records in determining the need for irrigation has been advocated for eastern apple orchards by Magness, Degman, and Furr (7).

TYPICAL ORCHARD RECORDS

Typical records for lemon orchards have been shown in figures 1, 2, and 3, indicating how fruits react to changes in the soil-moisture supply in orchards where considerable stress has been allowed to develop in the trees.

In figure 4 are shown the growth curves for navel oranges for two orchards on sandy loam soil. The field capacity of this soil is 12 percent. No measurable moisture deficit is indicated for orchard B with a 15-day interval between irrigations. Orchard A, with a 30-day irrigation schedule, developed appreciable moisture deficits before each irrigation. Before the irrigation on August 4 rolling of the leaves was visible evidence of a high stress for water.

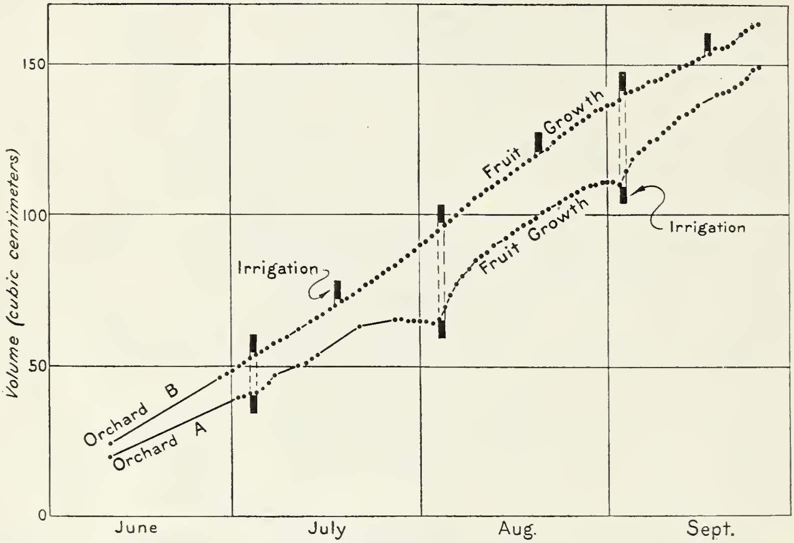

FIGURE 4.—Relation of fruit growth to irrigation interval for two navel orange orchards on a sandy loam soil at Pomona, Calif., 1934.

Records for two Valencia orange orchards are given in figure 5. Orchard J is on a very light sandy soil and orchard F on a heavy clay soil. Orchard J had a regular 15-day schedule for irrigation during the summer and yet the fruit measurements indicated stress for water in the trees in August and September. Irrigation in orchard F was irregular, the interval between irrigation sometimes being 2 months or more. At the September irrigation, some stress for water was evident from the fruit-growth records.

Both orchards showed depressions in the growth curves during December 13 to 17. On those dates temperatures dropped below 32° F. each morning, and the interval since irrigation had been greater than previously. The greatest shrinkage was shown by the fruit in orchard F, where the soil was very dry.

A record from a grapefruit orchard at Bard, Calif.,[2] 7 miles northwest of Yuma, Ariz., is shown in figure 6. The soil in this orchard is very sandy below the top foot.

[2] Furnished by D. W. Bloodgood, associate irrigation engineer, Division of Irrigation, Bureau of Agricultural Engineering, from data obtained in investigations on duty of water conducted in cooperation with the Bureau of Plant Industry.

Figures 5 and 6 illustrate how citrus fruits react to variations in soil moisture and to different irrigation treatments. When the fruits are green and growing vigorously, they are sensitive indicators of water deficit in the tree. Records of apparent growth rates are easily

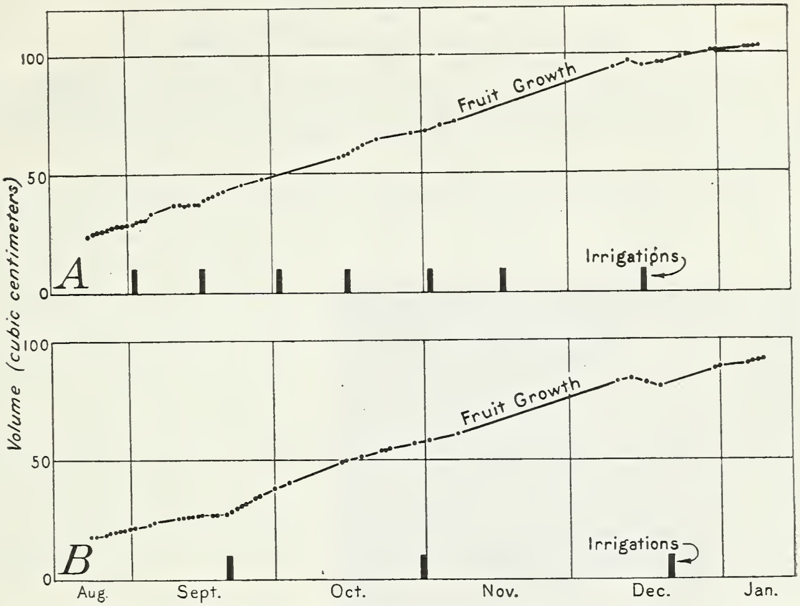

FIGURE 5.—Relation of fruit growth to irrigation interval for two Valencia orange orchards at San Dimas, Calif., 1935: *A*, Orchard J, on sandy soil; *B*, orchard F, on clay soil.

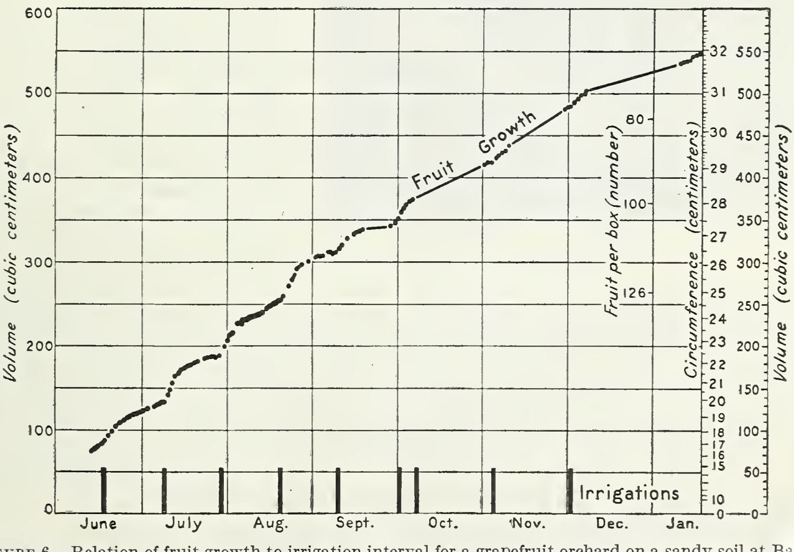

FIGURE 6.—Relation of fruit growth to irrigation interval for a grapefruit orchard on a sandy soil at Bard, Calif., 1935. Volumes plotted directly from circumference measurements by means of a special scale.

secured by daily measurements. As the soil becomes dry, the apparent growth of fruit declines. If the tree has been dry, a marked swelling of the fruit will be noted following irrigation. The relative magnitude of apparent growth rates before and after irrigation gives an indication of the degree of stress for water.

USE OF FRUIT-GROWTH RECORDS

By making use of this reaction of the fruit to moisture supply, the grower may obtain a measure of the effectiveness of irrigation practice and determine the interval between irrigations best suited for his conditions.

The term "apparent growth rates" is used by preference, because the water content of green, growing fruit is changing continually. Comparisons may be made of actual average growth rates as between plots over long intervals of time, such as a complete season; but for shorter periods of time, such as an interval between irrigations, quantitative differences are very apt to be masked by changes in water content of fruit. That the water content of green, growing fruit is continually changing throughout the day and also as time after irrigation increases, may be readily checked by some simple observations. The grower may do this by measuring the circumference of a green fruit several times during the day. If the measurements be made at 6 a. m., 10 a. m., 2 p. m., 6 p. m., 10 p. m., and 6 a. m. the next day, the daily cycle will be apparent. On hot days, the fruit will shrink measurably during the morning and early afternoon and swell again in the evening and during the night. A record of this type is shown in figure 7.

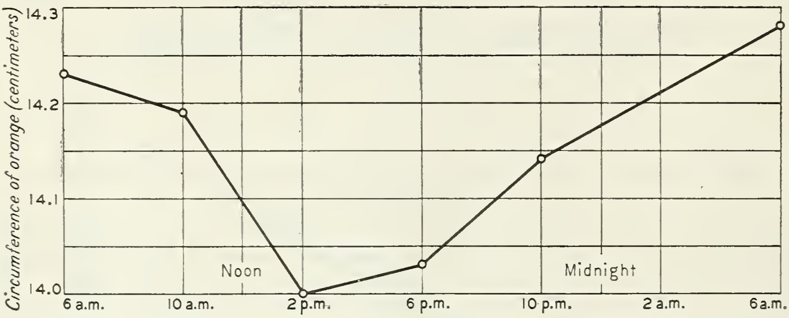

FIGURE 7.—Variation in size of fruit through a 24-hour cycle.

As time elapses after irrigation and the soil becomes dry, the recovery during the night will lag until finally there may be no apparent growth from day to day; or if the stress for water is further increased, the fruit may shrink. This was illustrated in figure 3 in which it was shown that the apparent growth rate of fruit slowed down from day to day from October 1 to 15, and after October 15 a daily shrinkage was recorded. This is evidence of a high stress for water, and it may be noted again that the soil was quite dry and yielded little water after October 15.

In figure 4 records are shown for two orchards with different intervals between irrigations. Fruit had apparently ceased growth for 7 days prior to the irrigation of orchard A on August 4. After the irri-

gation there was a rapid swelling for about 5 days and then a more regular increase from day to day. This reaction of the fruit to a changing moisture supply explains why the term "apparent growth rate" is preferred. It would be misleading to say that true growth rate of fruit declined to zero before irrigation and then accelerated for a few days following irrigation, because actually there is no evidence of such an occurrence. The marked changes in apparent growth rate before and after irrigation are evidence of changes in moisture content and this the grower may use in checking up on irrigation practices.

First attempts by the grower at using records of apparent growth rate of fruit should be limited to checking a few trees in the orchard where difficulty has been experienced with irrigation. Measurement must be made early in the morning because daily shrinkage may be measurable within 2 hours after sunrise, as indicated in figure 7. Ten to fifteen fruits may be measured and charted in ½ to 1 hour, and by a moderate start of this character the grower will learn something of the value of such records. Experienced workers, making regular daily measurements, will measure and chart records for 100 fruits in 1 to 2 hours depending on the location of the fruit in the orchard.

The most practical and accurate method of measuring fruit has been found to be by the use of a small, flexible, steel tape graduated in centimeters. Small, 1-meter, steel measuring tapes may be purchased from hardware dealers at small cost. These tapes are in flat, compact cases, about the diameter of a half dollar and may be conveniently carried in one's pocket.

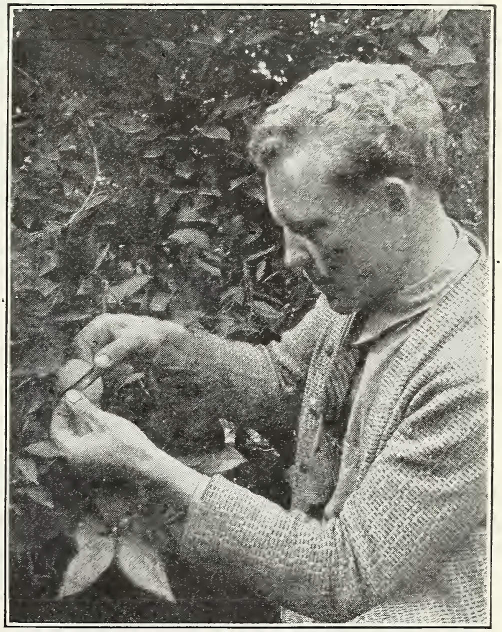

FIGURE 8.—Measuring the circumference of a fruit with a steel tape.

Measurement of a fruit is made by looping the tape around the fruit (fig. 8) at its largest diameter, holding the tape snugly but not tightly enough to compress the fruit. With a little practice one learns to gage the proper tension on the tape so that successive readings on the same fruit will check within two- or three-hundredths of a centimeter. The smallest graduations marked on the tape are one-tenth of a centimeter, but hundredths of a centimeter can be estimated very closely.

Two fruits per tree are suggested for initial attempts at obtaining records. It will be best to select the two fruits that are to be measured on the north or west side of the tree, away from the early morning sun. Green fruit at least 10 centimeters in circumference should be selected. Suitable green fruit may be found on lemon trees at all

seasons, but it is usually some time in June before oranges and grapefruit are large enough for satisfactory measurements.

If the selected fruit is smooth and is chosen in a position at eye level or lower, no trouble should be experienced in making accurate measurements. With a rough or irregular fruit, or after the fruit is larger, more difficulty may be experienced in making accurate measurements. When this is encountered, one may mark the fruit with india ink. To do this, place a small rubber band around the fruit at the maximum circumference. Then dip a piece of coarse thread in india ink and lay the thread along the upper side of the rubber band. This marking of the fruit should be done when the fruit is dry in order to make a clean, permanent line. When the ink is dry, remove the rubber band and make subsequent measurements with the tape set on the reference line.

The measurements should be recorded in tabular form so that a ready comparison may be made with the previous day's measurements as each value is set down (table 1). With a well-kept tabular record one may often determine the trend of growth by an inspection of the tabulated figures.

TABLE 1.—*Sample notes on measurements of oranges*

[Block A, row 9, tree 14, fruit no. 2]

Date, 1934	Time	Circumference	Date, 1934	Time	Circumference
	A.m.	*Centimeters*		*A.m.*	*Centimeters*
July 21	5:30	15.58	Aug. 5	5:45	16.38
July 28	6:00	15.79	Aug. 6	6:00	16.63
Aug. 1	5:45	15.73	Aug. 7	6:00	16.83
Aug. 2	6:00	15.69	Aug. 8	6:00	16.99
Aug. 3	6:00	15.76	Aug. 9	5:50	17.18
Irrigating today			Aug. 10	5:30	17.30
Aug. 4	5:30	16.10	Aug. 11	5:30	17.37

The best plan, however, is to keep a plotted record of each fruit in a manner to show increase in growth volumetrically. The circumference measurements may be converted to volume by the use of a conversion table. A conversion table that may be used for oranges and grapefruit is given in table 2 which shows the volume of a sphere for each one-tenth centimeter increase in circumference. For lemons, table 3 is used. This table was derived from an empirical curve based on determinations of the relation of the circumference to volume of a large number of lemons. Both of these tables list the relation by increases of one-tenth of a centimeter; readings to hundredths may be interpolated.

TABLE 2.—*Conversion table for oranges and grapefruit*

Circumference (centimeters)	0.0 cm	0.1 cm	0.2 cm	0.3 cm	0.4 cm	0.5 cm	0.6 cm	0.7 cm	0.8 cm	0.9 cm
	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³
5	2.1	2.2	2.4	2.5	2.7	2.8	3.0	3.1	3.3	3.5
6	3.6	3.8	4.0	4.2	4.4	4.6	4.9	5.1	5.3	5.6
7	5.8	6.0	6.3	6.6	6.8	7.1	7.4	7.7	8.0	8.3
8	8.6	9.0	9.3	9.7	10.0	10.4	10.7	11.1	11.5	11.9
9	12.3	12.7	13.2	13.6	14.0	14.5	14.9	15.4	15.9	16.4
10	16.9	17.4	17.9	18.5	19.0	19.6	20.1	20.7	21.3	21.9
11	22.5	23.1	23.7	24.4	25.0	25.7	26.4	27.0	27.7	28.5
12	29.2	29.9	30.7	31.4	32.2	33.0	33.8	34.6	35.4	36.3
13	37.1	38.0	38.8	39.7	40.6	41.5	42.5	43.4	44.4	45.4
14	46.3	47.3	48.4	49.4	50.4	51.5	52.6	53.6	54.7	55.9
15	57.0	58.1	59.3	60.5	61.6	62.8	64.1	65.3	66.6	67.9
16	69.2	70.5	71.8	73.1	74.5	75.9	77.2	78.6	80.1	81.5
17	83.0	84.4	85.9	87.4	88.9	90.5	92.1	93.6	95.2	96.9
18	98.5	100.1	101.8	103.5	105.2	106.9	108.7	110.4	112.2	114.0
19	115.8	117.7	119.5	121.4	123.3	125.2	127.2	129.1	131.1	133.1
20	135.1	137.1	139.2	141.3	143.4	145.5	147.6	149.8	152.0	154.2
21	156.4	158.6	160.9	163.2	165.5	167.9	170.2	172.6	175.0	177.4
22	179.8	182.3	184.8	187.3	189.8	192.3	194.9	197.5	200.2	202.8
23	205.5	208.2	210.9	213.6	216.4	219.2	221.9	224.8	227.7	230.5
24	233.4	236.4	239.3	242.3	245.3	248.3	251.4	254.4	257.6	260.7
25	263.9	267.0	270.3	273.5	276.7	280.0	283.3	286.7	290.0	293.4
26	296.8	300.3	303.7	307.2	310.7	314.3	317.8	321.4	325.1	328.7
27	332.4	336.1	339.8	343.6	347.4	351.2	355.0	358.9	362.8	366.7
28	370.7	374.7	378.7	382.7	386.8	390.9	395.0	399.2	403.4	407.6
29	411.9	416.1	420.4	424.8	429.1	433.5	438.0	442.4	446.9	451.4
30	455.9	460.5	465.1	469.8	474.4	479.1	483.9	488.6	493.4	498.2
31	503.1	508.0	512.9	517.8	522.8	527.8	532.8	537.9	543.0	548.2
32	553.4	558.6	563.8	569.1	574.4	579.7	585.1	590.5	595.9	601.4
33	606.9	612.4	618.0	623.6	629.2	634.9	640.6	646.3	652.1	657.9
34	663.7	669.6	675.5	681.5	687.4	693.4	699.5	705.6	711.7	717.8
35	724.0	730.3	736.5	742.8	749.1	755.5	761.9	768.3	774.8	781.3
36	787.9	794.5	801.1	807.7	814.4	821.2	827.9	834.7	841.6	848.5
37	855.4	862.3	869.3	876.3	883.4	890.5	897.7	904.9	912.1	919.3
38	926.6	934.0	941.3	948.8	956.2	963.7	971.2	978.8	986.4	994.0
39	1,001.7	1,009.4	1,017.2	1,025.0	1,032.9	1,040.8	1,048.7	1,056.6	1,064.6	1,072.7
40	1,080.8									

TABLE 3.—*Conversion table for lemons*

Circumference (centimeters)	0.0 cm	0.1 cm	0.2 cm	0.3 cm	0.4 cm	0.5 cm	0.6 cm	0.7 cm	0.8 cm	0.9 cm
	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³	*Cm*³
5	3.6	3.7	3.9	4.0	4.2	4.4	4.6	4.8	5.0	5.2
6	5.4	5.6	5.9	6.1	6.4	6.7	7.0	7.2	7.5	7.8
7	8.0	8.3	8.6	8.9	9.2	9.6	9.9	10.3	10.6	11.0
8	11.3	11.7	12.1	12.5	12.9	13.3	13.7	14.1	14.6	15.0
9	15.5	15.9	16.4	16.9	17.4	17.9	18.4	19.0	19.6	20.2
10	20.8	21.3	21.9	22.6	23.2	23.9	24.5	25.2	25.9	26.6
11	27.3	28.0	28.7	29.5	30.3	31.1	31.9	32.7	33.6	34.4
12	35.2	36.0	36.9	37.8	38.7	39.7	40.6	41.6	42.6	43.6
13	44.6	45.6	46.6	47.6	48.7	49.8	51.0	52.1	53.3	54.5
14	55.6	56.8	58.1	59.3	60.5	61.8	63.1	64.3	65.6	67.0
15	68.4	69.7	71.1	72.5	73.8	75.2	76.7	78.2	79.8	81.3
16	82.9	84.5	86.0	87.6	89.2	90.8	92.4	94.1	95.9	97.6
17	99.4	101.1	102.9	104.7	106.5	108.4	110.3	112.1	114.0	115.9
18	117.9	119.8	121.8	123.8	125.8	127.9	130.0	132.1	134.3	136.4
19	138.6	140.9	143.1	145.4	147.7	150.0	152.4	154.7	157.1	159.5
20	161.9	164.3	166.8	169.3	171.8	174.4	177.0	179.7	182.4	185.1
21	187.8	190.5	193.3	196.1	198.9	201.8	204.7	207.7	210.7	213.7
22	216.7	219.8	222.9	226.0	229.1	232.2	235.4	238.6	241.9	245.3
23	248.7	252.1	255.5	258.9	262.4	265.9	269.4	273.0	276.7	280.4
24	284.1	287.9	291.6	295.4	299.2	303.0	306.9	310.8	314.8	318.8
25	322.9									

The labor of making these tabular conversions may be avoided if use is made of a plotting scale properly graduated so that the conversion is automatically taken care of. Scales for plotting can be made up from the table given and ruled on durable paper. Volume should be ruled on the right-hand side and circumference on the left. Plotting scales of various sizes made up in this manner are shown in figure 9. When these plotting scales are used, the original circum-

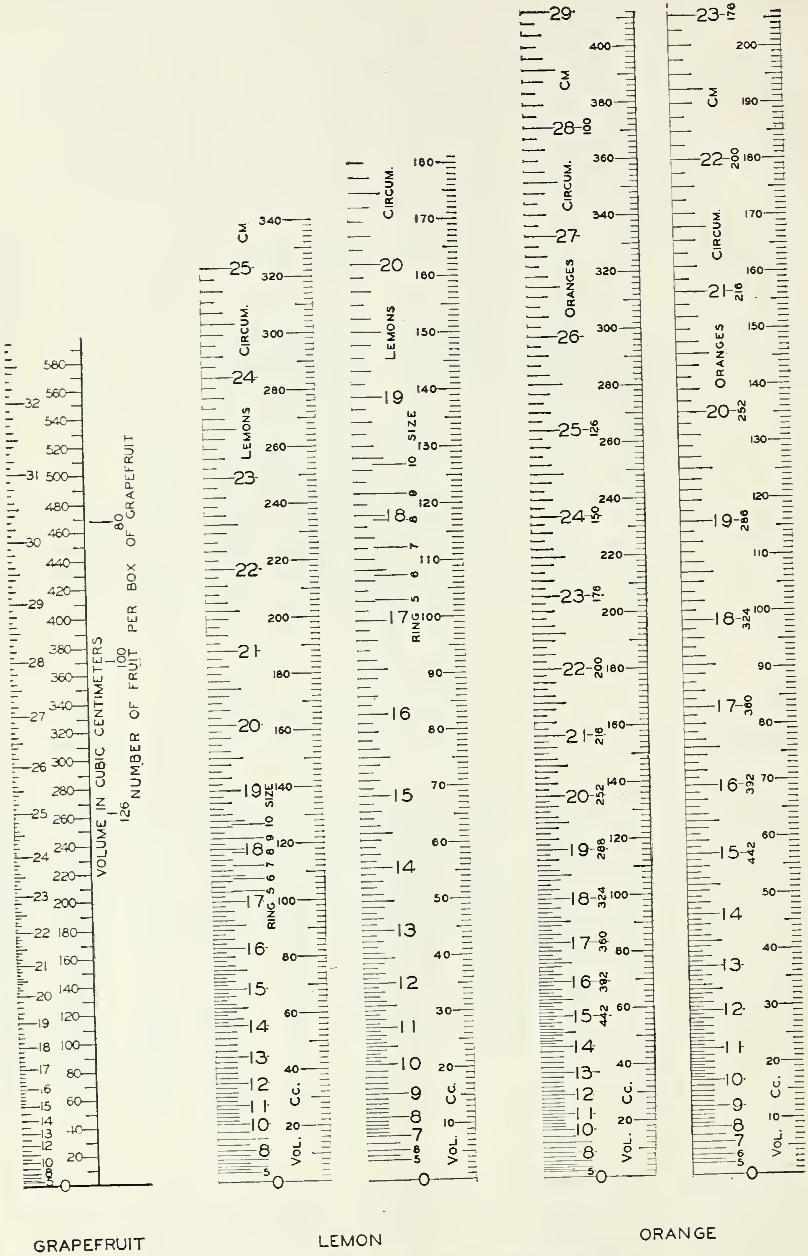

FIGURE 9.—Plotting scales for grapefruit, lemons, and oranges.

ference readings are plotted directly by use of the left-hand edge of the scale. The resultant graph is on a uniform volume scale. Use of a plotting scale is illustrated in figure 6.

The proper volume scale and the best time scale to select will depend on the conveniences at hand. Growth of oranges and lemons may be plotted satisfactorily on a time scale of 10 days to the inch, and on a volume scale of 20 cubic centimeters to the inch. For the larger grapefruit, a volume scale of 40 cubic centimeters to the inch is more satisfactory. The smaller scales make plotting tedious and scales as large as 5 days to the inch and 10 cubic centimeters to the inch may be used where a place is available for filing the larger sheets of paper needed.

In making use of these records, it should be remembered that the fluctuations in apparent growth rate give a relative index of stress for water in the tree. No attempt should be made to use the seasonal growth of one or two fruits on a tree as a measurement of true average growth of fruit for that tree. A much larger number of fruit and a more elaborate set-up are required for making comparison of seasonal growth between trees, plots, or orchards. One fruit, however, may supply evidence of stress for water, because the water system of the tree acts as a unit (*5*).

The grower will find records of growth of fruit of increasing value as more of them are accumulated and experience is gained, but initial efforts should be limited to checking the adequacy of established irrigation practices. Usually this will be merely a record showing the apparent growth rate of fruit in relation to irrigation. For a minimum expenditure of effort, measurements should be made early each morning for 3 days prior to irrigation and for 5 days following irrigation and at weekly intervals for the remainder of the period. In this way evidence will be obtained of the condition of the tree with respect to its water supply.

A decline in the apparent rate of growth of fruit prior to irrigation followed by a sharp increase after water is applied is evidence that there was a water deficit. No detrimental effects have been found from slight to moderate water deficits before irrigation, and no advantage was gained by irrigating so frequently that no measurable water deficit developed in the fruit. On the other hand, when intervals between irrigations were extended until apparent growth of fruit ceased, or when a moderate water deficit persisted for several weeks during the season, the ultimate size of fruit was less. A complete season's fruit-growth record will enable the grower to determine whether the irrigation intervals used were adequate to meet the needs of the trees.

USE OF SOIL-MOISTURE RECORDS

Soil-moisture records may also be used to determine the water supply to the tree, but the evidence is less direct. The soil around a tree may be examined thoroughly with the aid of a soil tube and samples may be taken for moisture-content determinations. From these records it is possible to determine the amount of water required to bring the soil up to field capacity. The zones with the greatest concentration of feeder roots are depleted of readily available mois-

ture first, and one method of procedure in soil-moisture control makes use of these zones of high feeder-root concentration.

Soil at a depth of 1 foot or more is not affected by surface evaporation and a reduction in moisture content at that depth may be attributed entirely to the action of roots. When the soil is well filled with roots, the moisture content may be reduced rapidly from field capacity down through the range of readily available moisture. After the readily available moisture has been extracted, plants must develop relatively high suction force for a further withdrawal of moisture from the soil. Wilting of the plant occurs when the moisture content of the soil is reduced appreciably below the range of readily available moisture. This may be illustrated by the record of extraction of moisture by a sunflower plant from a small mass of soil in a sealed container as in figure 10, *A*. This plant is one of a group used in a

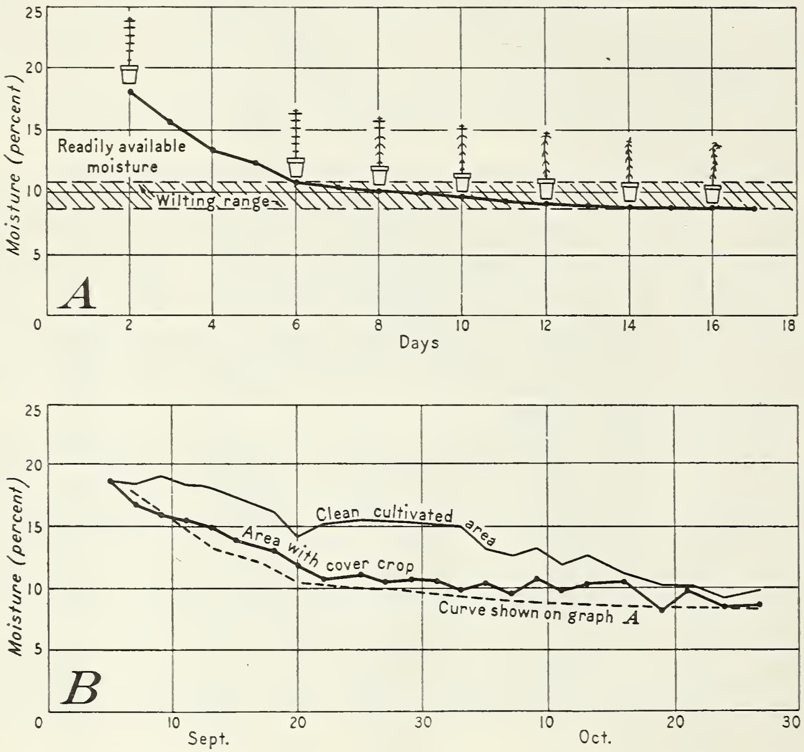

FIGURE 10.—*A*, Wilting of sunflower plant with depletion of soil moisture. *B*, Soil-moisture depletion in lemon orchard compared with that in sunflower pot.

series of wilting determinations on the soil for which orchard data were given in figure 3. In these tests the sunflower plants were grown until they were well established with four or more pairs of leaves. The soil in each container was then brought up to field capacity and each container sealed so that there would be no evaporation. Thus the sole loss shown in figure 10, *A* is by transpiration from the sunflower plant. From field capacity down to a moisture content of 11 percent, there was no apparent change in the appearance of the

plant. Below a moisture content of 11 percent, wilting of the lower, older leaves commenced. As the moisture content was further reduced, wilting progressed up the plant until finally it was completely wilted at a moisture content of about 9 percent. The range of moisture contents from field capacity down to 11 percent is referred to as the range of readily available moisture. Below this, wilting occurred and the moisture content from 11 to 9 percent is referred to as the wilting range for this particular soil. This is the critical range of moisture contents in which a progressive wilting of the sunflower plant took place in the test of this soil. The percentage might be different, of course, for other soil types.

If this laboratory record (fig. 10, *A*) is compared with the data collected on the same soil in the field (fig. 3), it may be noted from figure 3 that the same range in moisture content that was critical for the sunflower plant was also critical for the lemon tree. On September 30 the fruit was showing no water shortage and on that date 80 percent of the second foot of soil was in the range of readily available moisture. By October 23 the top 2 feet of soil had lost all of its readily available moisture and all samples showed moisture contents within the wilting range. The older, fall-set fruits had ceased to enlarge and were shrinking by October 15. Visible evidence of water shortage was furnished also by a slight rolling of the leaves at that time. The fruit-growth records indicate a gradually increasing stress for water between October 1 and 15 and the soil-moisture records during the same period show a gradually increasing proportion of the soil with readily available moisture exhausted. Hence the soil-moisture content of the principal feeder-root zones may be used as an index of the water supply available to the tree.

In making practical application to the orchard, the grower should first become familiar with the rooting habits of his trees. This can be done best by digging some trenches, and noting the principal zones of feeder roots. With the data from the trenches as a guide, a further and more general examination of the orchard soil may then be made by borings with a post-hole type of auger. This post-hole type of auger is recommended because sufficient soil is obtained for the examination for feeder roots.

If the grower wishes to become familiar with the soil-moisture characteristics in his orchard, he may do so by a rather simple field experiment in a portion of his orchard that is irrigated by furrows. On one side of a tree in the area along the tree line not normally irrigated a cover crop is established. This cover crop may consist of any of the volunteer plants which ordinarily grow in the orchard, preferably of the broad-leaved type. The other side of the tree along the unirrigated tree line is kept clean-cultivated. With the cover crop well established, the test is commenced by a thorough irrigation of the test tree, wetting all of the soil including the test areas on both sides of the tree. The test areas on each side of the tree are then blocked off and no further water is applied to them, although regular irrigation is given in the usual furrows. Care must be taken to prevent the water from the regular irrigation furrows penetrating into the test areas. Notes are kept on the condition of the cover crop with particular reference to the time and degree of wilt. Rain, of course, would interfere with this experiment, but in the Southwest, periods will occur that are without rain long enough to complete the test.

After the irrigation, soil samples are collected at regular intervals with a small post-hole type of auger. The samples are taken from a depth of about 1 foot below the ground surface and placed in air-tight containers. Cans with tight lids may be used or 1-pint fruit jars with a tight seal will serve the purpose. Each container is labeled or marked to show the date and depth of sampling. If laboratory facilities are available, a portion of each soil sample is oven-dried and the moisture content determined. The original samples will furnish a graded series of moisture contents for later inspection.

A test so carried out will acquaint the grower with the moisture characteristics of the soil in his orchard. If moisture contents are determined, the records may be plotted as in figure 10 *B* and the range of readily available moisture determined. In this figure it may be noted that there was a rapid extraction of moisture until the moisture content was reduced to 11 percent. After that it was lost at an extremely slow rate from the area with cover crop. This establishes the end of the range of readily available moisture, and when the soil moisture is 11 percent or less irrigation is required.

When without facilities for determination of the moisture content of the samples, the grower must rely on the wilting of the cover crop to establish the lower limits of readily available moisture. Just after irrigation the soil may be described as wet. Then as it is reduced in moisture content it may be judged as moist, partly moist, partly dry, and finally, dry when the cover crop shows the first signs of wilt. Broad-leaved plants droop, grass blades roll and then wither and become dry and brown.

From figure 10, *B* it may be noted that the moisture content of the soil is reduced much more quickly when a cover crop is grown. The cover crop requires additional water and more frequent irrigation. However, the roots of the lemon tree alone finally reduced the moisture content of the soil to nearly the same value as where there was a cover crop.

With a record of this character before him the grower will have a basis for determining when the readily available moisture has been extracted from the soil. In this example, the change in slope of the soil-moisture curve indicates 11 percent as the safe lower limit for soil-moisture contents. Values appreciably below 11 percent would be taken as evidence that the tree is under considerable stress for water.

At the end of the test, the grower should examine the samples saved in the sealed cans or jars to become familiar with the appearance and feel of the soil at various moisture contents. By removing only a small part of the soil from each container, he may keep the graded series serviceable for some time. With some soils the moisture content may be judged closely from the appearance and feel, but others cannot be judged so readily.

This field method of determining the minimum moisture content of the soil, which may be desirable before irrigation, will be the most practical for the grower's use. Laboratory methods may be used but these require more experience. The wilting point established from a moisture-equivalent determination divided by 1.84 (*4*) is applicable to certain soils. With many soils, however, this method gives neither the true field capacity nor the correct wilting point (*10*).

Wilting points may also be determined by laboratory experiments in which plants, such as sunflowers, are grown in small containers filled with the soil under test. However, difficulties will be experienced in arriving at a value that may be safely used as the minimum moisture content for the orchard soil at the time of irrigation. Wilting occurs in a relatively narrow range of soil-moisture content, but it is progressive and various stages of wilt may be recognized. This was illustrated in figure 10 which is now referred to again for further discussion.

A laboratory determination with a sunflower plant is shown in figure 10, *A* and the orchard records on the same soil in figure 10, *B*. The first signs of wilting were evident at 11 percent moisture content, but there was a continued withdrawal of moisture from the soil. As the moisture content was further reduced, wilting progressed up the plant until ultimately the plant was completely wilted at about 9 percent moisture content of the soil. This ultimate condition of wilt has been termed the ultimate wilting point (*9*). The wilting range in this soil is from 11 to 9 percent—a range of 2 percent in moisture content. The plant will revive and continue growth if water is added to the soil at any time during the stages of wilt indicated in figure 10, *A*. Native plants will reduce the soil to the same moisture content in the field, but they will also be reduced to similar stages of wilt. Obviously in a properly irrigated orchard the moisture content of the soil, below the depth to which evaporation is effective, will never reach such low values. The orchard tests (fig. 10, *B*) indicate that irrigation is required at a soil-moisture content of 11 percent. In a pot experiment, however, the moisture content of the soil may be easily reduced to a point corresponding to an advanced stage of wilt and trouble will be experienced in attempting to dry the orchard soil to a similar degree. Hence, experimental determinations of wilting points in small pots should be used with caution. The safer plan is to use the field test under orchard conditions as previously described.

After the grower has established the minimum moisture content desirable before irrigation, use is made of the soil-sampling records from the feeder-root zones. When the determinations show moisture contents at the desired minimum or slightly above it, the time of irrigation is decided upon. It may be needed very quickly or there may be a long period in which the actual date of application is of little consequence. Two examples were given in figures 1 and 2. Records from the zones of greatest feeder-root concentration will give advance indication of the need for irrigation. Fruit-growth records will show whether the time of irrigation may be further delayed. Finally a complete inspection of the orchard soil will show the extent to which the soil has been dried out and where the irrigation water may be applied to the best advantage.

The principal period when the fruit-growth records may be used to advantage is from June to October. This is particularly so for oranges and grapefruit. At other seasons, and especially in the spring when fruit is setting, soil moisture must serve as the principal guide for irrigation.

PROCEDURE AND EQUIPMENT

Key locations in the orchard for regular soil sampling should be chosen in relation to the irrigation system. For example, with

furrow irrigation locations may be selected near the upper and lower ends of furrows, near trees that may be receiving the most water, and also near those that may be receiving the least water. If only one sampling location is to be used near a certain tree, it should be located in the area or furrow receiving the most irrigation water.

Sampling may be done with a 3-inch post-hole auger of the type illustrated in figure 11. Soil samples should be collected from a depth of 1 foot or more, from soil in which feeder roots are observed. The moisture content of these samples will give the first indication of impending water shortage and need for irrigation. A soil-sampling location may be chosen at the spread of the tree on the southeast or southwest side of the tree, in soil wetted at each irrigation.

FIGURE 11.—Soil sampling with a 3-inch post-hole auger.

FIGURE 12.—Soil sampling with standard soil tube.

Fruit should be tagged on the west or north side of the same tree. Smooth, green fruit should be selected, 10 or more centimeters in circumference. Measurements should be made and recorded in the manner described on pages 10 to 15.

For the rapid general inspection of the orchard soil for moisture conditions, there is no better equipment than the soil tube (*11*). A convenient soil tube for use in citrus orchards is one 4 feet 6 inches long and a 14-pound hammer is satisfactory for most soils (fig. 12).

Heavier hammers weighing about 25 pounds are more effective when the soil is rocky or compact. Ordinarily the tube may be withdrawn with the aid of the hammer, but when the soil is exceptionally tight, a jack (*8*) may be necessary for pulling the tube. The heavier hammer and the soil-tube jack are shown in figure 13.

On a sandy loam or soil of lighter type, the soil tube may also serve to check the penetration of irrigation water while it is still on the land. When more clay is present in the soil, the core may stick in the soil tube if the soil is wet. In such cases the check-up on penetration of irrigation water must be deferred for perhaps 4 or more days after irrigation.

A ready means of checking the depth of penetration while water is actually on the land is by use of a probe. Many growers make constant use of a probe, testing the penetration in each furrow before the water is turned off. The lubricating property of water is made use of in its operation. The probe is pushed into the soil about 6 inches in a furrow where water is running and then withdrawn so that water flows into the hole (fig. 14). The probe is then pushed

FIGURE 13.—Heavy equipment for soil sampling under difficult conditions. A 25-pound hammer is used to drive the tube and a jack is used for pulling it.

down the hole again and on through the wet soil until dry soil is reached. Progress of the probe will stop abruptly at the depth of penetration of moisture from the furrow in most soils, provided the underlying soil is reasonably dry.

When first using a probe, it will be wise to check the initial tests with borings made alongside the furrow with a soil tube or auger. The probe is usually satisfactory for tests to a depth of 3 feet or less. A probe made of 7/16-inch dural metal rod may be purchased for $1 or less and weighs less than a pound. There is some flexibility in the rod which aids in slipping past rocks. Steel rods may also be used and a tine from an old hay rake makes a satisfactory probe. When

conditions are right, there is no easier or better way of checking penetration than with a probe.

SUMMARY

Citrus growers will find both soil-moisture and fruit-growth records useful in checking up on irrigation practices. During the principal irrigation season from June to October, fruit-growth records serve as a valuable guide in determining the effectiveness of irrigation. Fruit-growth and soil-moisture conditions may be correlated during this period and the extent and depth of the root zone established.

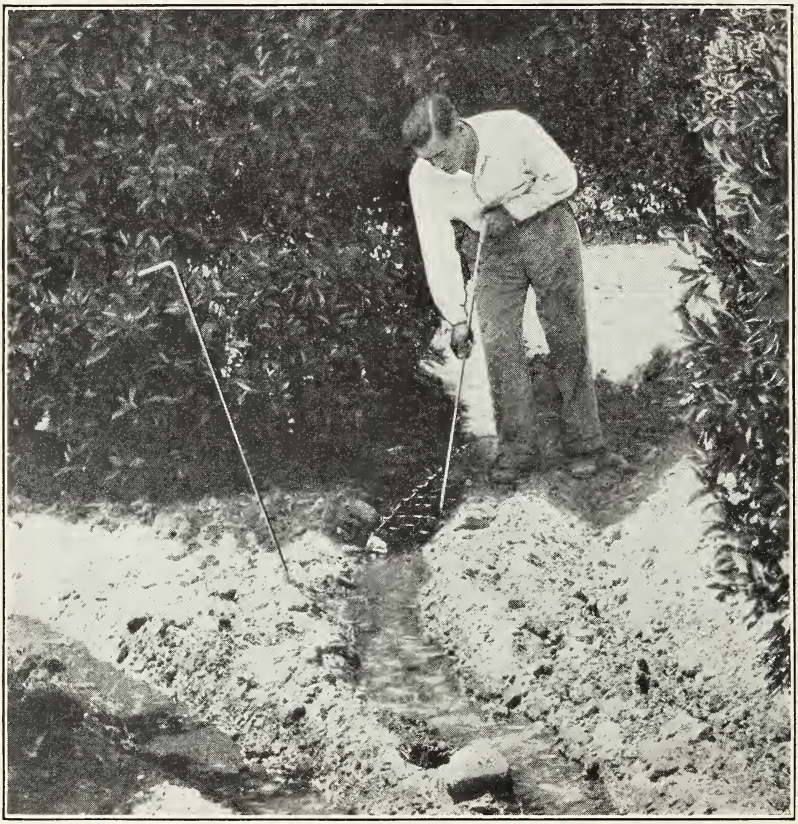

FIGURE 14.—Use of probe in checking depth of penetration of water in furrow.

Soil samples taken in the zones of soil most thoroughly permeated by feeder roots will give the first indication that the supply of readily available moisture is becoming exhausted. A general inspection of the orchard soil will then show the extent to which the soil is dry and what penetration should be secured when water is applied. Each furrow or border check may be probed while the water is on the land to determine whether the desired penetration is being obtained.

Fruit measurements taken before and after irrigation will indicate, by the relative rate of apparent growth, whether or not there was any

unusual stress for water in the tree at the time of irrigation. From these growth records, it may be determined whether the interval between irrigations is satisfactory.

The necessary equipment for the average orchard is not expensive nor is the procedure difficult. The grower will be well repaid for the time and effort expended on both soil-moisture tests and fruit measurements. With a season's record before him the grower may decide what modifications are necessary in order to improve his irrigation program.

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